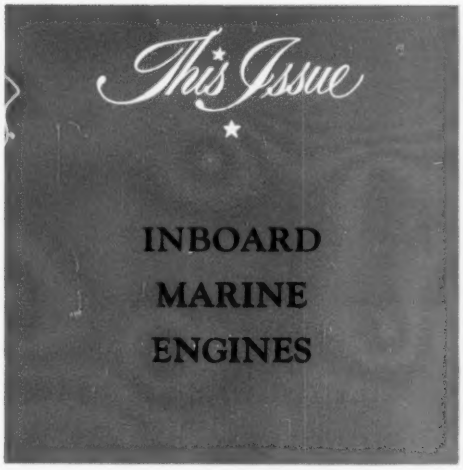
Volume 45 JUNE, 1959 Number 6

Lubrication

A Technical Publication Devoted to the Selection and Use of Lubricants



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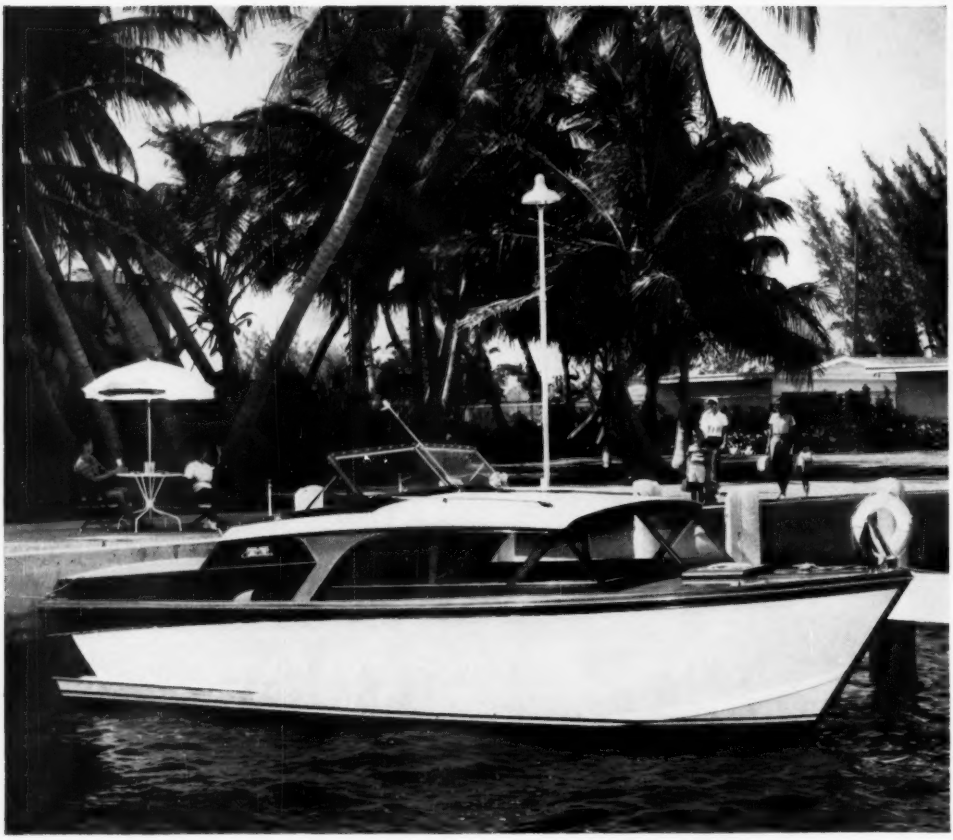

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LUBRICATION

A TECHNICAL PUBLICATION DEVOTED TO THE SELECTION AND USE OF LUBRICANTS

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Inboard Marine Engines

PLEASURE boating probably dates back to prehistoric times when man first learned to fashion crude rafts from fallen trees. It was many thousands of years after these early beginnings before man was able to replace muscle and wind power with engine power. The earliest of the self propelled vessels were nothing more than sailing ships which utilized steam engines to supply motive power. Robert Fulton's Clermont, built in 1807, was one of the first such ships which did not have to rely on the capriciousness of the winds. Needless to say, the early steam engines were cumbersome and bulky, and not at all suited for small craft. It was not until the invention of the gasoline and diesel engines in the nineteenth century that inboard engines for small boats became feasible. Through the design efforts of the engine manufacturers, and the improvements in fuels and lubricants by the petroleum industry, the internal combustion engine was developed to a point where it was practical for marine use. Within the past fifty years inboard marine engines have been developed and produced in this country to an extent where they are now within the economic grasp of almost any person who desires to own a power boat.

STATISTICS

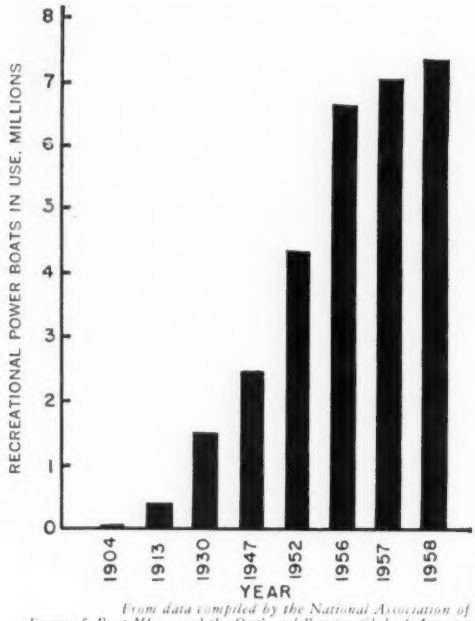
The actual growth of pleasure boating has been phenomenal. As may be seen from Figure 1 the number of recreational boats in use following World War II up to the present has trebled. Of the engines used to power these boats about 12 per cent are inboard engines. Approximately eighty-five per cent of the inboard engines presently being produced are gasoline units as opposed to diesel. The impact of all this on the petroleum industry may be seen from the fact that in 1958 these pleasure boats consumed over 400 million gallons of gasoline, 22 million gallons of diesel fuel and 20 million gallons of lubricating oil.[1]

ENGINE TYPES

Today's inboard marine engines may be divided into two general classifications, gasolines and diesel. Either classification may employ a two stroke or a four stroke cycle; in the vast majority of inboard marine engines the four stroke cycle is used. Tomorrow's engines may very well include a third classification, the gas turbine. The gas turbine power plant shown in Figure 2 has been installed in both Navy and commercial craft.

This article will be concerned primarily with inboard engines of the reciprocating type used in small to medium sized craft, and the greatest part of the discussion will center about gasoline engines which are used in about 85% of the nearly one million inboard powered pleasure craft estimated to be in operation today. Good maintenance practices, for example, are not restricted to engine type, but apply equally well to all engines.

[1]From data compiled by the National Association of Engine and Boat Mfrs., and the Outboard Boating Club of America.



From data compiled by the National Association of Engine & Boat Mfrs., and the Outboard Boating Club of America

Figure 1 — Growth of Pleasure Boating.

Marine inboard engines can be divided into several groups, depending upon the number of cylinders, cylinder arrangement, valve arrangement, horsepower or cooling systems. Cylinder arrangements consist of the single cylinder (Figure 6); the familiar inline multi-cylinder engine, (Figures 3, 7, 8, 9, 14) and the V type engine (Figures 4, 5, 10, 11). In recent years the V-engine has become quite popular due to its low silhouette, compactness and high output per unit size.

Valve arrangement may be either L-head (Figures 3, 6, 7) or valve-in-head (Figures 4, 5, 8, 9, 10, 11, 14) with both the in-line and V-engine. The number of cylinders may range from one to twelve. The one and two cylinder engines, Figures 6 and 7, are quite frequently used in commercial craft such as fishing boats or as auxiliary engines in pleasure craft. Horsepower may range from two to over three hundred. The trend is towards higher compression ratio, higher horsepower engines. Most of the inboard engines in use today are liquid cooled; however, air cooled engines, Figure 8, are available.

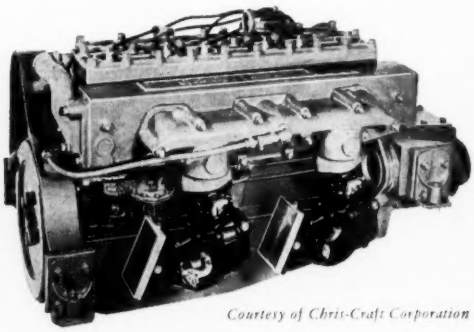
MARINE ENGINE DESIGN

Most pleasure-boat marine engines bear some resemblance to their automotive cousins, especially with such items as cylinder blocks, pistons and cylinder heads; however, because of the large differences encountered in operating conditions and environment, the marine engine poses its own special design and performance problems.

It must be realized that the marine engine is called upon to run steadily at fairly high speeds under medium to heavy load conditions; whereas its automotive counterpart operates intermittently over a wide range of speeds and loads. For this reason some marine engine components must be more rugged than those used in passenger car engines and in fact are more closely akin to truck engines. Exhaust valve life, for instance, is largely dependent upon the operating temperatures of the valves themselves. Since the valves in a marine engine are subject to prolonged operation at high temperatures, heavy-duty valve gear components, such as sodium cooled valves, high alloy valve seat inserts and positive valve rotators, are often used. Other heavy duty parts such as hardened crankshafts, copper-lead crankshaft and connecting rod bearings and corrosion resistant valve springs, may also be employed.

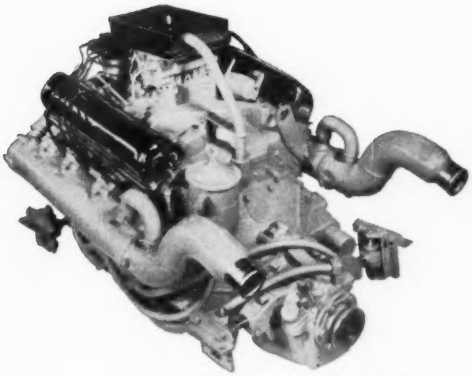
Courtesy of Solar Aircraft Company

Figure 2 — Engine of the future? One of two Gas Turbines used for propelling a crew boat.



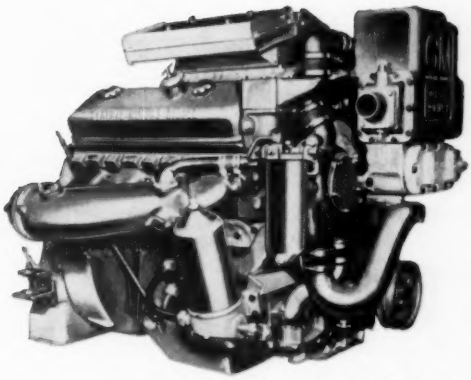
Courtesy of Chris-Craft Corporation

Figure 3 — A six-cylinder L-Head engine employing dual up-draft carburetion.



Courtesy of Dearborn Marine Engines, Inc.

Figure 4 — A modern V-8 engine utilizing a four-barrel carburetor. Note the flame arrestor and crankcase breather tube.



Courtesy of Detroit Diesel Engine Division General Motors Corporation

Figure 5 — A V-8 two-cycle Diesel engine.

Of considerable importance in present day marine engine design are the physical aspects of size and weight. With the increase in consumer demands for engines of greater horsepower, size and weight have become a prime factor in the selection of an engine for a particular boat. In this regard, the marine engine industry faces much the same problem as the automotive industry; that of increasing power output, mechanical, thermal, and volumetric efficiencies of a given engine without changing its basic structure. Power increase may be attained by a variety of means such as increasing the displacement or raising the compression ratio. Turbocharging, illustrated in Figure 9, and fuel injection, shown in Figure 10, may also be used. The problem of weight is somewhat aggravated by the use of such necessary items as water-jacketed exhaust manifolds, oil coolers and cast oil pans. Through economical design practices and the judicious use of lightweight materials, the overall engine weight may be kept at an acceptable level.

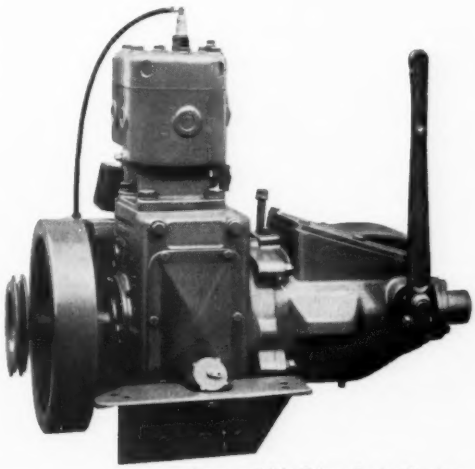
Carburetion and Ignition

Carburetors used on marine engines fall into three general classifications: up-draft (Figures 3, 6), side-draft (Figure 11) and down-draft (Figure 4). Up-draft and side-draft carburetors are used to a great extent to decrease overall engine height. Wholly unlike automotive power plants, marine engines must usually be installed in restricted inaccessible spaces where any accidental leakage can only collect in the bilge. Most marine carburetors, therefore, have an anti-drip feature. Flame arrestors, which are used in place of air cleaners, are also standard equipment of marine engines. Many gasoline and diesel engines incorporate a crankcase breather system that delivers crankcase fumes to the air intake system as shown in Figures 4, 9, 10, and 11. When the engine is running this feature helps to minimize odor in the engine compartment.

The ignition systems are very similar to those found in automotive use with perhaps some accent on waterproofing. The control of spark advance on a marine engine need not be quite as flexible however, since throttle opening and load are constant for any given engine speed. For this reason many marine engines use a centrifugal type spark advance which is sensitive to speed changes only.

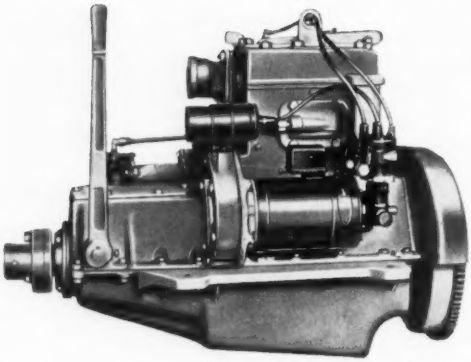
Cooling Systems

With the exception of a few engines that are air cooled, most marine engines are cooled by pumping



Courtesy of The Palmer Engine Company

Figure 6 — A small four-cycle single-cylinder gasoline marine engine with manually controlled reverse gear.



Courtesy of Universal Motor Company

Figure 7 — A two-cylinder 12 H.P. L-Head gasoline engine.

either fresh, treated sea, or raw sea water directly through the engine cooling jackets. The pump itself must be capable of providing sufficient coolant during engine idling periods and (unlike the automotive pump) is usually of the positive displacement type. Either before or after the coolant has passed through the cylinder block and head passages it is routed through the jacketed exhaust manifolds to keep exterior engine temperatures at a low level. The water is finally disposed of by emptying it into the engine exhaust line.

In order to minimize low temperature engine deposits, engine jacket temperature should be maintained at a minimum of 150°F., and preferably higher. Operation of an engine at excessively lower temperatures will result in a decrease in thermal efficiency and promote low temperature sludge, wear and corrosion. These factors will be discussed in more detail under fuels and lubricants.

However, if salt water is being use as the direct coolant and its temperature exceeds 150°F., destructive scale and deposits tend to form in the cooling system. For example, salt deposits around exhaust valve seats may cause valve burning. It should be noted that the temperature limitation imposed by salt water as a direct coolant, is in direct opposition to the statements made in the preceding paragraph.

To eliminate the direct salt water cooling problem, a closed fresh water cooling system such as that shown in Figure 12, may be employed. This system is similar to that used in an automobile except that the conventional radiator is replaced with a heat exchanger, and sea water rather than air is used as the cooling medium. Two pumps are normally required, one to circulate fresh water through the engine and one side of the heat exchanger, and another to circulate sea water through the other side of the heat exchanger. It is possible to eliminate one pump by placing the heat exchanger along the keel of the boat, thus submerging the heat exchanger in sea water.

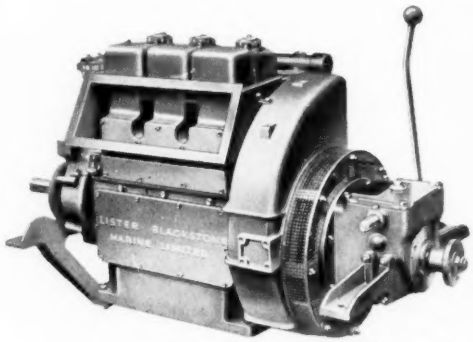
As mentioned previously, maintaining proper engine temperatures is a very important factor in the performance and life of a marine engine. Coolant temperatures may be controlled in one of two ways: either manually, with a throttling valve controlling the amount of water recirculating through the system, or automatically with a thermostat.

Lubrication Systems

The lubrication system is one of the major factors contributing towards dependability and durability in any internal combustion engine. Almost all marine engines manufactured at the present time use a full pressure lubrication system, as opposed to the splash system. In the full pressure system (see Figure 13) oil from the crankcase is pumped under pressure, by a positive displacement type pump, to an oil gallery or distribution line. From the gallery, oil is sent to the crankshaft main bearings, the connecting rod bearings, camshaft bearings and the valve train assembly. Hydraulic valve lifters, if used, are fed directly from the oil gallery.

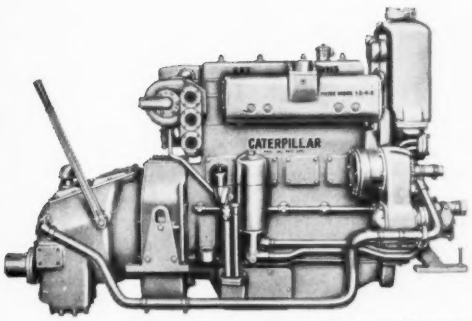
Oil filters are used on most marine engines. The two types in general use are the full-flow and the by-pass type. In the full-flow type, *all* of the oil must pass through the filter on its way from the crankcase to the oil gallery. Should the filter become clogged, a by-pass line shown in Figure 13, is incorporated so that the flow of oil to the gallery will not be interrupted. In the by-pass type of filtering system only a portion of the oil from the pump is passing through the filter at any moment. Eventually, however, all of the oil is filtered.

Since the flow of air through a marine engine compartment is not always adequate to keep the oil temperature at a reasonable level, it is often necessary to use an oil cooler with the lubricating system.



Courtesy of Lister-Blackstone, Inc.

Figure 8 — An air cooled three-cylinder Diesel engine.



Courtesy of Caterpillar Tractor Company

Figure 9 — A 4-cylinder turbocharged Diesel marine engine.

The oil cooler is nothing more than a simple heat exchanger which has engine coolant flowing through one side and lubricating oil through the other.

Crankcase oil temperatures should not be allowed to rise over 230°F. Excessively high oil temperatures cause oxidation of the oil and the attendant formation of high temperature sludge, varnish deposits, and piston ring sticking.

ENGINE LUBRICATING OILS

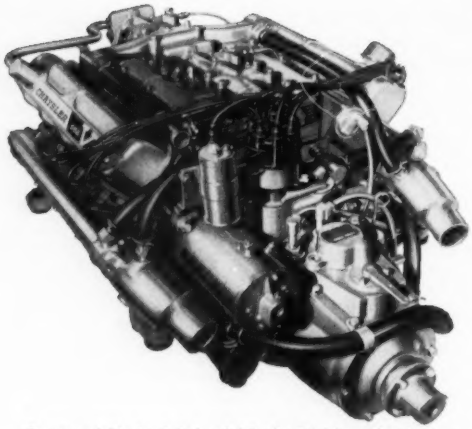
In addition to its primary function of reducing friction, a crankcase oil must also prevent wear, cool bearings, retard the formation of deposits and prevent rust and corrosion. Today's quality motor oils may contain one or a combination of different types of additives to aid the oil in performing these functions. Under moderate or severe engine operating conditions at both high and low temperatures the use of additives can enhance the oil's performance immeasurably.

Probably the most severe engine operating condition occurs at low temperature. Low coolant and oil temperatures result from short cruises wherein the engine does not have sufficient time to warm up. At such times the important crankcase oil temperature lags behind coolant temperature by an hour or more. The engine is considered to be operating as a "cold" engine when the *crankcase oil temperature is below 140°F.*, even though the coolant water temperature is above 140°F. The operation is even more severe if *both* oil and water temperatures are below 140°F. When coolant temperature is below 140°F., the water vapor, which is formed during the combustion of the fuel-air mixture, condenses on the cylinder walls and is carried into the crankcase by the action of the oil rings. Also, with a cold engine, the fuel is not burned as completely as in a warm engine. Some of the harmful products of incomplete combustion are fuel soot, unburned liquid fuel, acids and varnishes. Unless counteracted with a suitable oil, these materials mix with the oil and water to form a soft grey paste known as low temperature sludge. If the oil does not keep this material dispersed, it will deposit on engine parts, plug oil coolers and stick hydraulic valve lifters. Oil rings are also quite susceptible and may become plugged with resultant high oil consumption. Water, resulting from condensation in the engine, also combines with other products of the incomplete combustion to form acidic materials which are corrosive to engine parts such as piston rings and cylinder walls and cause high engine wear. Water also causes rusting of iron or steel engine parts unless protected by the oil. In addition to sludge, rust and corrosion, low temperature engine operation also results in the oil becoming diluted with unburned liquid fuel. This diluted oil is then scraped off the cylinder walls by the oil rings and carried into the crankcase. In addition to washing the oil film off the cylinder walls, the fuel reduces the viscosity or "dilutes" the oil. If cold operation is prolonged, dilution may reduce the viscosity of the oil to such an extent that it can no longer provide a sufficiently thick film of oil between moving parts; this promotes rapid engine wear and higher "oil" consumption.

At the opposite end of the severity scale is engine operation at high temperature. The crankcase oil, when exposed to high temperature for a sufficiently long period of time, will combine chemically with the oxygen in the air. The rate at which oxidation progresses depends to a large degree upon temperature, the higher the temperature the greater the tendency to oxidize. In some engine installations,

Courtesy of Flagship Marine Engines, Inc.

Figure 10 — A high speed V-8 marine engine with fuel injection.



Courtesy of Marine & Industrial Engine Division, Chrysler Corp.

Figure 11 — A V-8 engine employing dual side-draft carburetion and hydraulically controlled reverse gear.

high oil temperature may occur during extended high speed engine operation unless prevented by some device such as operable oil cooler of adequate size.

Oil Type

A superior additive-type oil must be used to protect the engine from the many undesirable effects arising from marine engine operation under severe conditions. A superior additive-type oil will contain adequate amounts of an effective oxidation inhibitor, a corrosion and rust protective, a detergent-dispersant additive, and an anti-foam agent. Oils which bear API Service Designations* of at least MS and DG are widely available and will give excellent protection to four-cycle gasoline engines. Diesel engine oils (API Service Designations DG, DM or DS) also give superior performance in four-cycle gasoline engines.

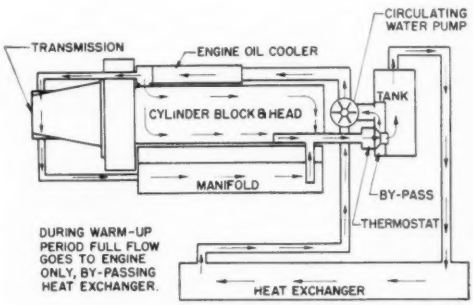
Oil Drain Intervals

The life of the crankcase oil is determined by its initial quality and by the type of service to which it is subjected. Additives wear out. The physical capacity of any oil to contain fuel soot is definitely limited. No oil nor oil filter can prevent fuel dilution. Therefore the only method of removing all these contaminants from the engine is to replace the oil at correct intervals. Since operating conditions vary so widely, there is no such thing as an "average" operation and a specific answer can not be given which will be correct for all. Engine manufacturers usually recommend replacement of the oil every 50 to 100 hours. Since the restricted nature of many engine installations will prevent *draining* the oil, it must be *pumped* out instead, therefore an oil that prevents deposit formation is all the more necessary. In cases where virtually all of the operation is of the short-cruise low-temperature type, the oil drain period should be even more frequent. For the majority, a 50 hour drain period is more realistic since service conditions are rarely ideal. A 100 hour drain period should be used only if service conditions are actually ideal, for example, use of a fresh water cooling system where jacket temperatures can be kept high and where most of the engine time is accumulated on extended cruises.

* See Magazine LUBRICATION, February 1959.

FUEL REQUIREMENTS

High output marine inboard engines have gasoline requirements similar in many respects to the modern automotive engine. The trend in design is towards high-output high-compression engines which demand a high octane gasoline to prevent detonation, "knock" or "ping". Attempted use of a gasoline with too low an octane number can lead to numerous engine difficulties such as power loss, broken cylinder head gaskets, burned or cracked pistons, broken piston rings and burned valves. Knock-free operation is important in any gasoline engine but it is vital in the marine engine because of the conditions under which this type of engine must operate. To illustrate, the octane requirement of an automobile engine is generally highest at low or medium engine speeds during full throttle acceleration. Consequently, if gasoline octane is too low under these conditions, the resulting knock will occur only momentarily and disappear as engine speed increases. This momentary knock, although ineffective and wasteful of power, will probably not cause immediate nor serious damage. The marine engine, however, cannot operate at full throttle and low speed because the boat's propeller allows the engine to speed up as soon as the throttle is opened.



Courtesy of Gray Marine Motor Co.

Figure 12 — Schematic diagram of a closed fresh water cooling system.

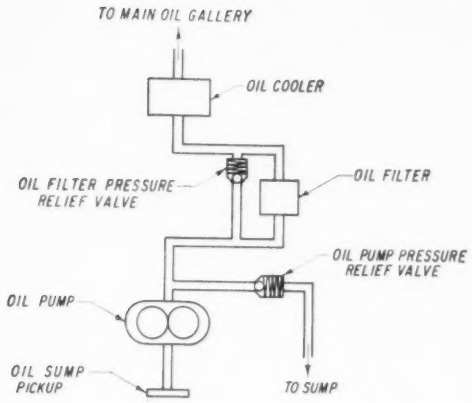


Figure 13 — Schematic diagram of a full pressure lubrication system employing a full-flow oil filter and oil cooler.

The highest engine octane requirement therefore occurs when the marine engine is operating steadily at high speed *and* high load. Since the marine engine may operate for considerable periods of time under these severe conditions, too low an octane number will result in continuous damaging knock. Unfortunately, wind and wave noise may prevent this knock from being heard with the result that engine damage or complete engine failure may occur without warning.

Any attempt to utilize a low octane gasoline by retarding ignition timing excessively is ill advised since it may cause power loss, poorer fuel economy, an overheated engine and burned exhaust valves.

"Marine white" gasolines* have an octane number of only about 80. Leading engine manufacturers now recommend high octane leaded marine gasolines available from several reputable refiners and some engine manufacturers even warn against the marine white type.

MARINE TRANSMISSIONS

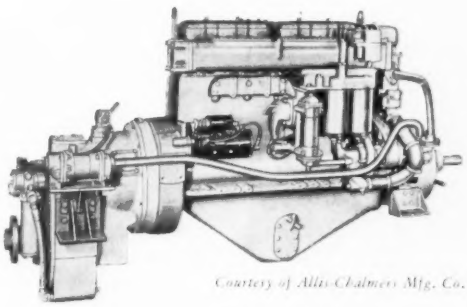
Perhaps one of the most deceptively simple looking pieces of equipment found on practically all inboard marine engines is the transmission. Its importance should not be underemphasized; aside from functioning as a means of reversing the propeller all transmissions provide a neutral position and some also serve as speed reduction units between the engine and propeller shaft. Reduction units are often necessary to operate a large boat with a high speed engine.

Many of the first marine engines utilized only a clutch to provide forward and neutral, and some were connected directly to the propeller shaft. With the increase in engine speeds and the desire for better boat maneuverability, the need developed for a marine transmission. The early transmissions took many forms; however, the one type which has evolved from the early designs is the planetary transmission. Planetary gearsets consist of a center or sun gear and an internal or ring gear which are interconnected by means of planetary pinion gears and controlled by "brake" bands or clutches. By locking any two of the gear train members direct drive may be obtained. By holding a particular member of the gearset stationary, a speed reduction is usually obtained. If none of the members of the unit are held stationary a neutral effect is attained. By using either a compound planetary with its two sun gears (Figure 15) or a simple planetary with two sets of pinions (Figure 16), a reverse ratio is obtained.

Until quite recently clutches and bands on most transmissions were applied mechanically by means of a hand lever. A demand arose for an easier and a remotely controlled means of shifting these transmissions which led to the development of hydraulically actuated marine transmissions. Hydraulic pressure is supplied by a pump which is generally driven from the input shaft at engine speed. This pressure is directed through passageways by means of a manual valve and is used to actuate servo pistons which operate the clutches and/or bands. Hydraulically operated transmissions almost always have their own lubrication system which is separate from that of the engine.

Marine transmissions are often cooled by water-jacketing the transmission case, or through the use of an external oil cooler.

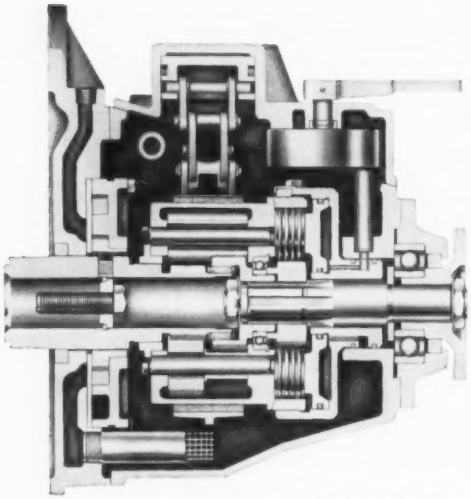
The lubricants used in marine transmissions vary all the way from extreme pressure gear lubricants to motor oils and automatic transmission fluids. This wide variance in lubricants is due to design differences between the various transmissions. The fluid



Courtesy of Allis-Chalmers Mfg. Co.

Figure 14 — A naturally aspirated six-cylinder, four-cycle Diesel engine.

* For more complete discussion, see Magazine LUBRICATION, June 1958, Pages 82 through 86.



Courtesy of Paragon Gear Works

Figure 15 — Cross-section of a hydraulically-operated marine transmission which uses a band and multi-disc clutch to control its compound planetary gear.

used in a hydraulically shifted transmission, for instance, must serve as a hydraulic medium for the fairly complex control system, besides acting as a lubricant and as a heat transfer medium. It is very important that the proper lubricant, obtained from a reputable refiner, be used to obtain long life and dependability from the marine transmission. Two widely used marine transmissions are shown in Figures 15 and 16.

MAINTENANCE SUGGESTIONS

Although the inboard marine engine and transmission are tough, rugged pieces of machinery, they, like all mechanical devices, require a certain amount of maintenance. Just a few hours and dollars spent each year on maintenance will be well rewarded with years of trouble-free operation.

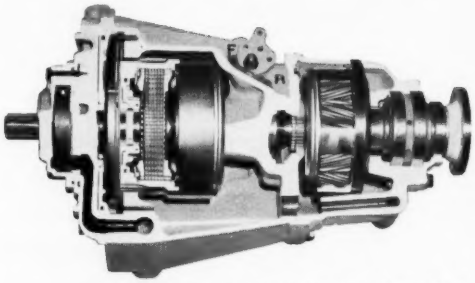
The following might serve as a partial check list of basic items which should receive periodic attention:

1. Check the crankcase and transmission oil levels before every trip, and make oil changes as dictated by the severity of operation.

2. Refill fuel tanks at every opportunity.

3. During fitting out, check the electrical system, particularly the cleanliness and gap adjustment of distributor breaker points and spark plugs.

4. During fitting out, carefully check the fuel tanks, fuel lines and fittings, filters, pump, and carburetors for leaks. Drain completely before laying up.



Courtesy of Warner Gear Division, Borg Warner Corp.

Figure 16 — Partial section of a hydraulically-operated marine transmission which employs two multi-disc clutches to control its simple planetary gear.

5. During fitting out, remove and clean flame arrestors by washing in kerosine. Clean air cleaners where used. Wash crankcase ventilator or oil fill cap in kerosine.

6. The cooling system should also be inspected regularly for leaks. If a closed fresh water cooling system is used the proper water level should be maintained. Thermostats should be inspected each season, especially when used in a direct salt water cooling system.

7. While underway, it is a good habit to regularly check the oil pressure and the temperature.

8. Such easy-to-overlook items as changing the oil filter, checking the battery water level and lubricating the water pump should not be neglected.

9. Keep bilge pumped out.

Any inboard marine engine and transmission with proper care, will give many years of dependable operation.

SUMMARY

Present day inboard marine engines have come a long way since the early days of weighty, bulky and inefficient engines. Transmissions have also made great strides over the years and have contributed considerably to boating enjoyment. Boating as a sport has been made economically available to almost anyone who desires to participate. These advances in boating have been made possible through the cooperative efforts of the boat, engine and transmission manufacturers, along with the petroleum industry. With the quality engines, transmissions, fuels and lubricants now available, today's inboard boat owner can expect many years of efficient, pleasurable boating.

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